

## CLAIMS

What is claimed is:

- 1     1.     A method of modeling a complex process having a plurality of input variables, a  
2     portion of which have unknown behavior that can be described by a function comprising  
3     at least one unknown parameter and producing an output that is a predictor of outcome of  
4     the process, the method comprising the steps of:  
5         providing a non-linear regression model of the process comprising:  
6             a plurality of first connection weights that relate the plurality of input  
7     variables to a plurality of process metrics; and  
8             a function and a plurality of second connection weights that relate input  
9     variables in the portion to the plurality of process metrics, wherein each of the plurality of  
10    second connection weights correspond to an unknown parameter associated with an input  
11    variable in the portion; and  
12    using the model to predict an outcome of the process.
- 1     2.     The method of claim 1, wherein the model has at least a first hidden layer and a  
2     last hidden layer, the first hidden layer having a plurality of nodes each corresponding to  
3     input variables in the portion, each node in the first hidden layer relating to an input  
4     variable with the function and a second connection weight, the second connection weight  
5     corresponding to the at least one unknown parameter.
- 1     3.     The method of claim 2, wherein the last hidden layer is connected to nodes in the  
2     first hidden layer and nodes associated with input variables that are not in the portion.
- 1     4.     The method of claim 3, wherein the function comprises two unknown parameters  
2     and can be represented by a first function with a first unknown parameter and a second  
3     function with a second unknown parameter, the method further comprising:  
4         providing a non-linear regression model of the process comprising:  
5             a first hidden layer, a second hidden layer, and a last hidden layer, the  
6     second hidden layer having a plurality of nodes each corresponding to one of the plurality  
7     of nodes in the first hidden layer,  
8             a first function and a plurality of second connection weights that relate  
9     input variables in the portion to nodes in the first hidden layer, wherein each of the  
10    plurality of second connection weights correspond to a first unknown parameter  
11    associated with an input variable in the portion;



- 9 (c) determining an error signal for the model;  
 10 (d) adjusting the one or more unknown parameters of the function and the  
 11 plurality of connection weights in a single process based on the error signal; and  
 12 (e) repeating steps (c) and (d) until a convergence criterion is satisfied.
- 1 12. The method of claim 11 wherein:  
 2 a portion of the input variables are input variables for a first hidden layer of the  
 3 non-linear regression model, the first hidden layer having a plurality of nodes each  
 4 associated with one of the input variables of the portion and having a single synaptic  
 5 weight;  
 6 the identified function relates to an input variable from the portion;  
 7 the error signal is determined for an output layer of the non-linear regression  
 8 model; and  
 9 the error signal is used to determine a gradient for a plurality of outputs of the first  
 10 hidden layer.
- 1 13. The method of claim 11, wherein the function is non-linear with respect to the  
 2 input variable.
- 1 14. The method of claim 13, wherein the input variable represents a time elapsed  
 2 since an event associated with the complex process.
- 1 15. The method of claim 11, wherein the input variable in the portion of the plurality  
 2 of input variables are maintenance variables of a complex manufacturing process.
- 1 16. The method of claim 11, wherein the function is an activation function of the  
 2 form  
 3 
$$\exp(-\lambda_j y_j)$$
  
 4 where  $\lambda_j$  is the synaptic weight associated with an input  $y_j$ , and the input  $y_j$  is an input  
 5 variable of the portion of the plurality input variables.
- 1 17. The method of claim 16, wherein the adjustment is of the form  
 2 
$$\Delta\lambda_j = -\eta y_j \delta_j$$
  
 3 where  $\eta$  is a learning rate parameter,  $\delta_j$  is the gradient of an output of a node  $j$  of the first  
 4 hidden layer with the input  $y_j$ ,  $\Delta\lambda_j$  is the adjustment for synaptic weight  $\lambda_j$  associated with

5 the input  $y_j$ , and the input  $y_j$  is an input variable of the portion of the plurality input  
6 variables.

1 18. An article of manufacture comprising a computer-readable medium having  
2 computer-readable instructions for  
3 determining an error signal for an output layer of a non-linear regression model of  
4 a complex process, the model having a plurality of input variables of which a portion are  
5 input variables for a first hidden layer of the model having a plurality of nodes, each node  
6 associated with one of the input variables of the portion and having a single synaptic  
7 weight;  
8 using the error signal to determine a gradient for a plurality of outputs of the first  
9 hidden layer;  
10 determining an adjustment to one or more of the synaptic weights corresponding  
11 to one or more unknown parameters of a function; and  
12 evaluating a convergence criterion and repeating foregoing steps if the  
13 convergence criterion is not satisfied,  
14 wherein the computer-readable medium is in signal communication with a  
15 memory device for storing the function and the one or more synaptic weights.

1 19. An article of manufacture for building a non-linear regression model of a complex  
2 process having a plurality of input variables, a portion of which have unknown behavior  
3 that can be described by a function comprising at least one unknown parameter and  
4 producing an output that is a predictor of outcome of the complex process, the article of  
5 manufacture comprising:  
6 a process monitor for providing training data representing a plurality of input  
7 variables and a plurality of corresponding process metrics;  
8 a memory device for providing the function and a plurality of first weights  
9 corresponding to the at least one unknown parameter associated with each of the plurality  
10 of input variables in the portion; and  
11 a data processing device in signal communication with the process monitor and  
12 the memory device, the data processing device receiving the training data, the function,  
13 and the plurality of first weights, determining an error signal for the non-linear regression  
14 model; and adjusting (i) the plurality of first weights and (ii) a plurality of second weights

15 that relate the plurality of input variables to the plurality of process metrics, in a single  
16 process based on the error signal.

1 20. The article of manufacture of claim 19, wherein the function is non-linear with  
2 respect to the input variable.

1 21. The article of manufacture of claim 19, wherein the function is an activation  
2 function of the form

3 
$$\exp(-\lambda_j y_j)$$
  
4 and wherein the adjustment is of the form

5 
$$\Delta\lambda_j = -\eta y_j \delta_j$$

6 where  $\lambda_j$  is the synaptic weight associated with an input  $y_j$ , the input  $y_j$  is an input variable  
7 in the portion,  $\eta$  is a learning rate parameter,  $\delta_j$  is the gradient of an output of a node  $j$  of  
8 the first hidden layer with the input  $y_j$ , and  $\Delta\lambda_j$  is the adjustment for synaptic weight  $\lambda_j$   
9 associated with the input  $y_j$ .

1 22. The article of manufacture of claim 19 wherein the data processing device further  
2 determines if a convergence criterion is satisfied.

1 23. The article of manufacture of claim 19 wherein the process monitor comprises a  
2 database.

1 24. The article of manufacture of claim 19 wherein the process monitor comprises a  
2 memory device including a plurality of data files, each data file comprising a plurality of  
3 scalar numbers representing associated values for the plurality of input variables and the  
4 plurality of corresponding process metrics.

1 25. An article of manufacture for modeling a complex process having a plurality of  
2 input variables, a portion of which have unknown behavior that can be described by a  
3 function comprising at least one unknown parameter and producing an output that is a  
4 predictor of outcome of the complex process, the article of manufacture comprising:

- 5 a process monitor for providing a plurality of input variables;  
6 a memory device for providing a plurality of first connection weights that relate  
7 the plurality of input variables to a plurality of process metrics, the function, and a  
8 plurality of second connection weights corresponding to the at least one unknown

9 parameter associated with each of the plurality of input variables in the portion; and  
10 a data processing device in signal communication with the process monitor and  
11 the memory device, the data processing device receiving the plurality of input variables,  
12 the plurality of first connection weights, the function, and the plurality of second  
13 connection weights; and predict an outcome of the process in a single process using the  
14 plurality of input variables, the plurality of first connection weights, the function, and the  
15 plurality of second connection weights.